Best Available Copy

# (12) UK Patent Application (19) GB (11) 2 377 928 (13) A

(43) Date of A Publication 29.01.2003

(21) Application No 0118253.4

(22) Date of Filing 26.07.2001

(71) Applicant(s)
**Finch Limited**
**(Incorporated in the Bahamas)**
**Trade Winds Building, Bay Street,**
**P.O. Box N-215, Nassau, Bahamas**

(72) Inventor(s)
**Arsene Badalov**

(74) Agent and/or Address for Service
**Frank B Dehn & Co.**
**179 Queen Victoria Street, LONDON,**
**EC4V 4EL, United Kingdom**

(51) INT CL[7]
C02F 1/44

(52) UK CL (Edition V)
C1C CSL C302 C460
B1X X6B1

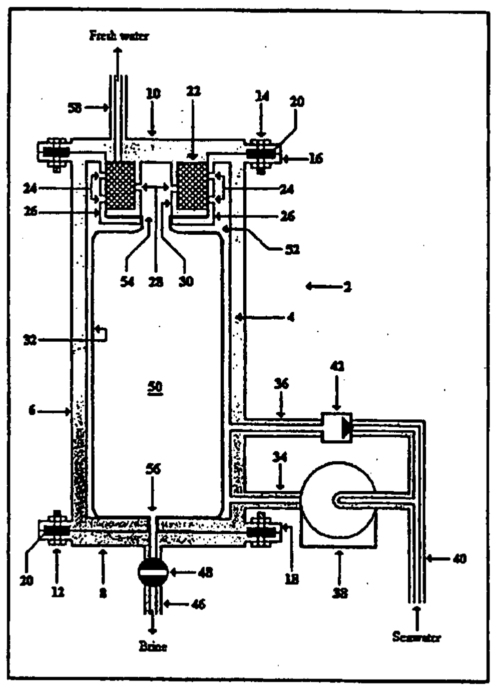
(56) Documents Cited
US 4604194 A

(58) Field of Search
UK CL (Edition T) C1C CRL CSL, U1S
INT CL[7] C02F 1/44
Other: ONLINE: WPI, EPODOC, JAPIO

(54) Abstract Title
**Desalination system**

(57) The invention relates to apparatus and methods of desalinating seawater utilising, in particular, but not exclusively, low pressure reverse osmosis using hollow fibre desalination membranes. A seawater desalination unit 2 comprising a storage tank 4 having a membrane separation module 22 provided in or on the storage tank. The storage tank is provided with sea water inlets 34, 36, a permeate outlet 58, a retentate outlet 56. A flexible, impermeable barrier 32 is arranged within the tank to define two variable volume chambers within the tank. The tank sea water inlet and the separation module inlet are in communication with one of the chambers and the separation retentate outlet is in communication with the other variable volume chamber. In use the storage tank is filled with pressurised seawater. The seawater is fed to the separation module to produce a fresh water product which exits from the storage tank, and a relatively dense, pressurised, retentate brine stream which flows back into the storage tank but is separated from the seawater already in the tank by means of the flexible barrier. This acts to assist the displacement of the seawater in the tank into the separation module.

Figure 1




GB 2 377 928 A

**Figure 1**

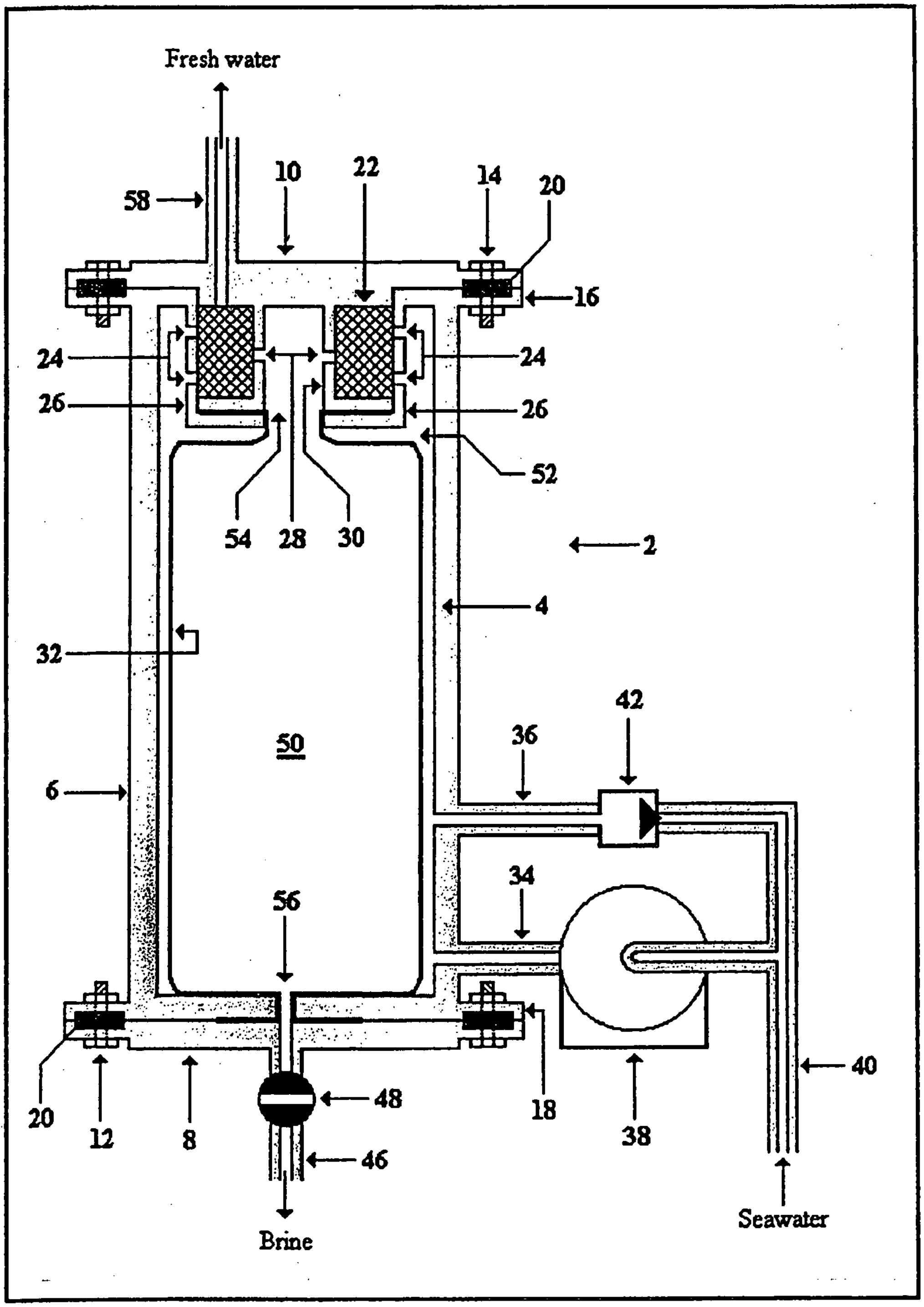

Fresh water
58
10
22
14
20
16
24
24
26
26
52
54
28
30
2
4
32
42
36
50
6
34
56
20
12
8
48
18
38
40
46
Brine
Seawater

Figure 2

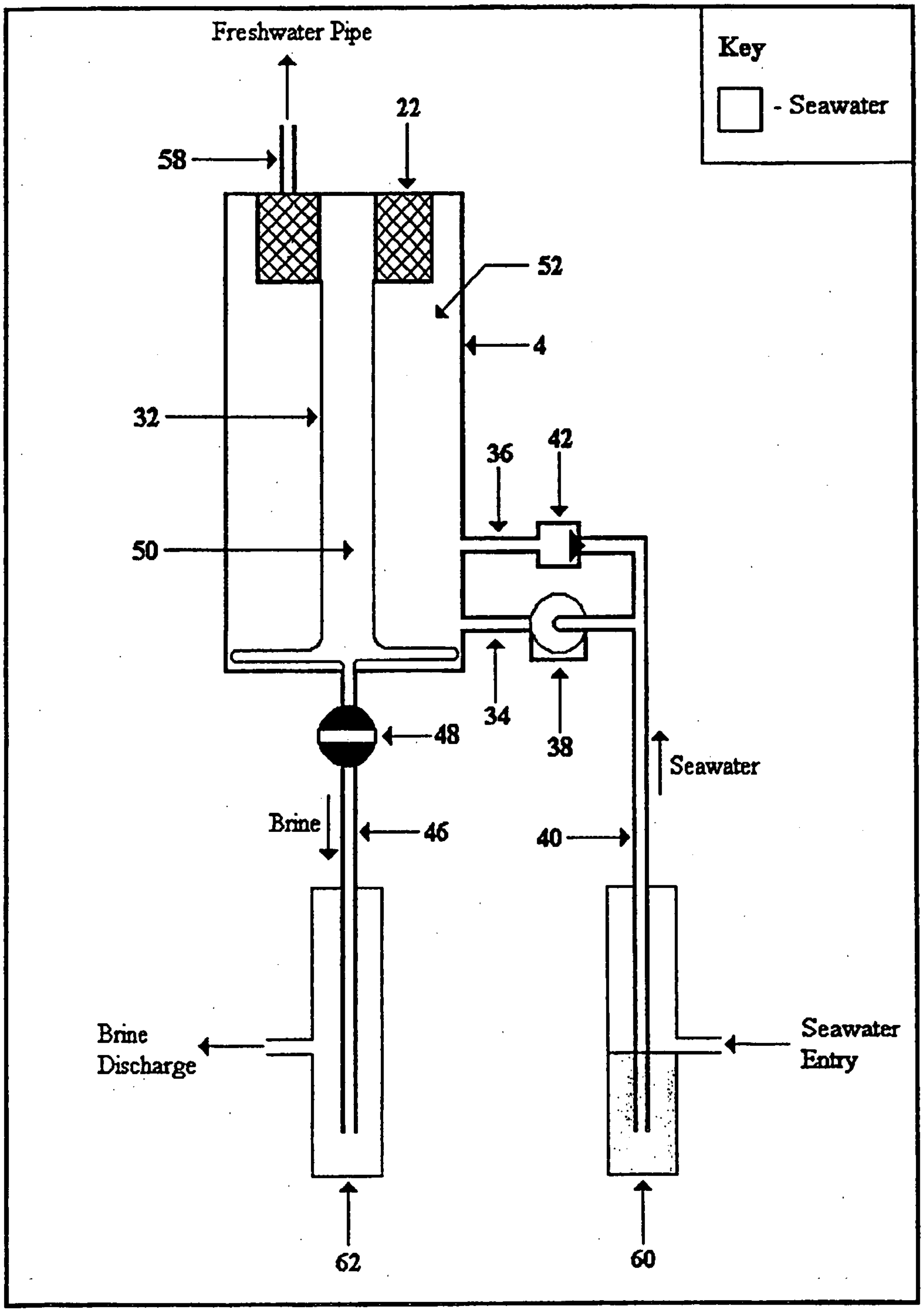

Freshwater Pipe
Key
- Seawater
22
58
52
4
32
36
42
50
34
38
48
Seawater
Brine
46
40
Brine Discharge
Seawater Entry
62
60

**Figure 3**

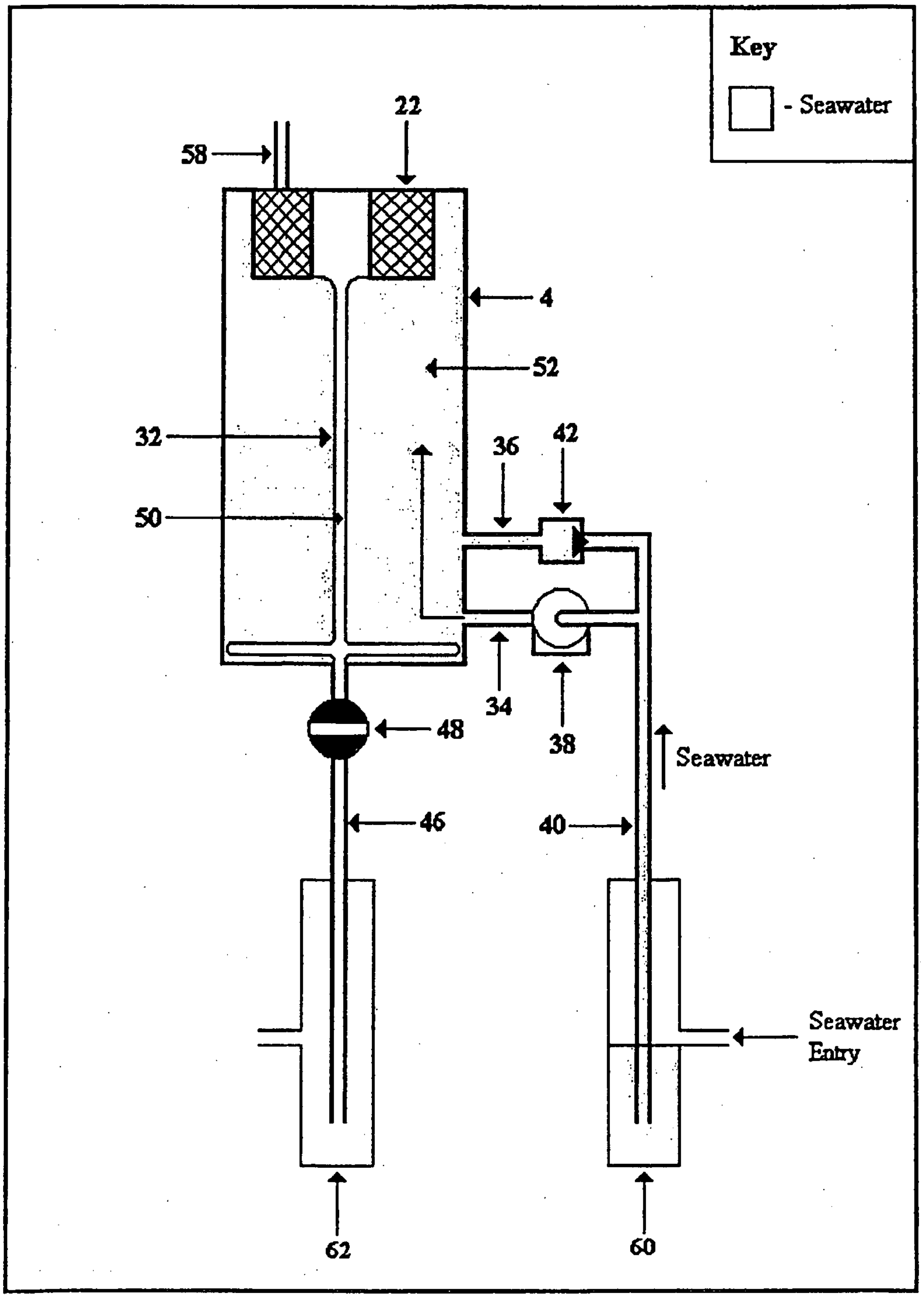

Key
- Seawater
22
58
4
52
32
36
42
50
34
38
48
Seawater
46
40
Seawater Entry
62
60

Figure 4

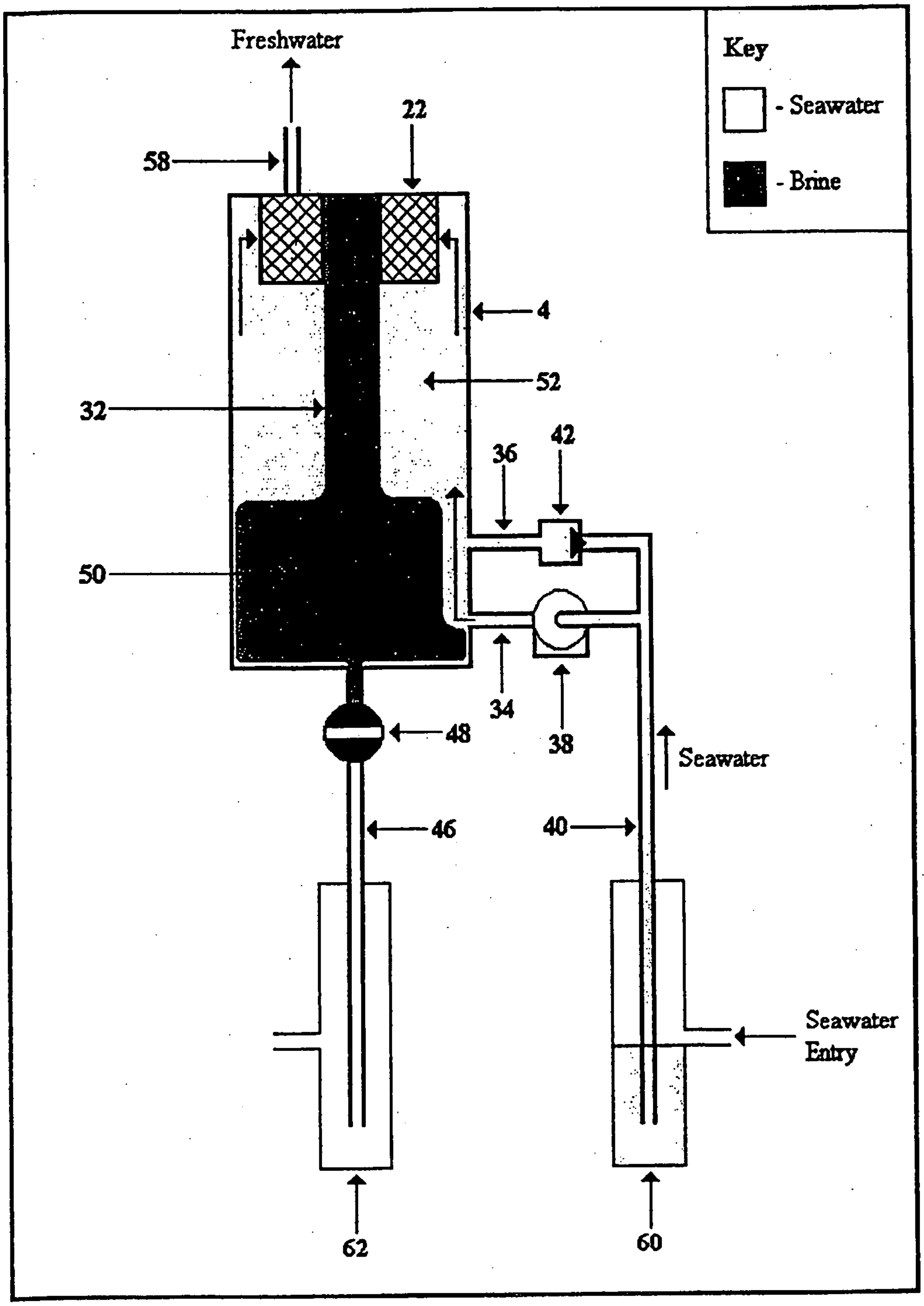

Freshwater
22
58
4
52
32
36
42
50
34
38
48
Seawater
46
40
Seawater
Entry
62
60
Key
- Seawater
- Brine

Figure 5

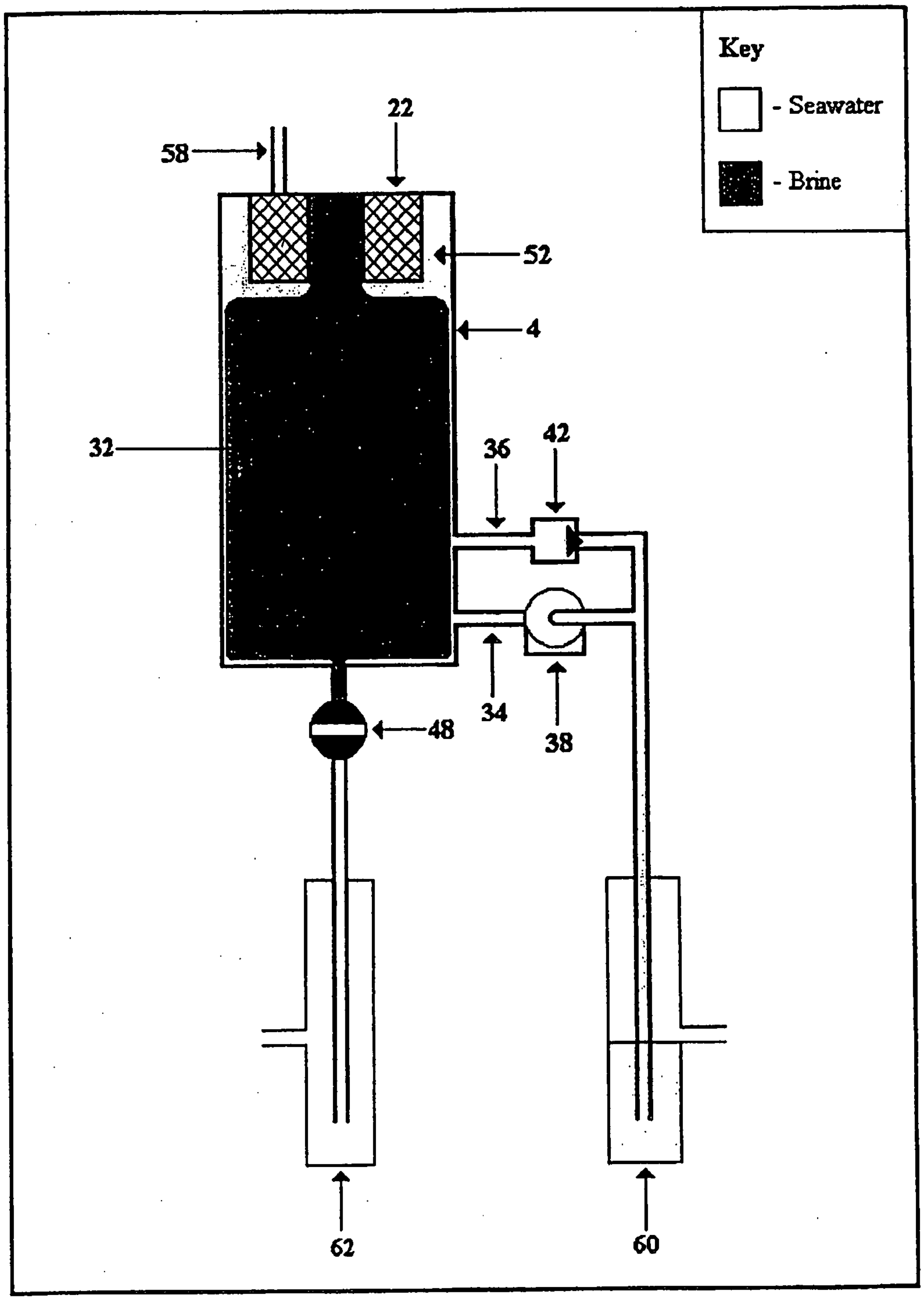


Figure 6

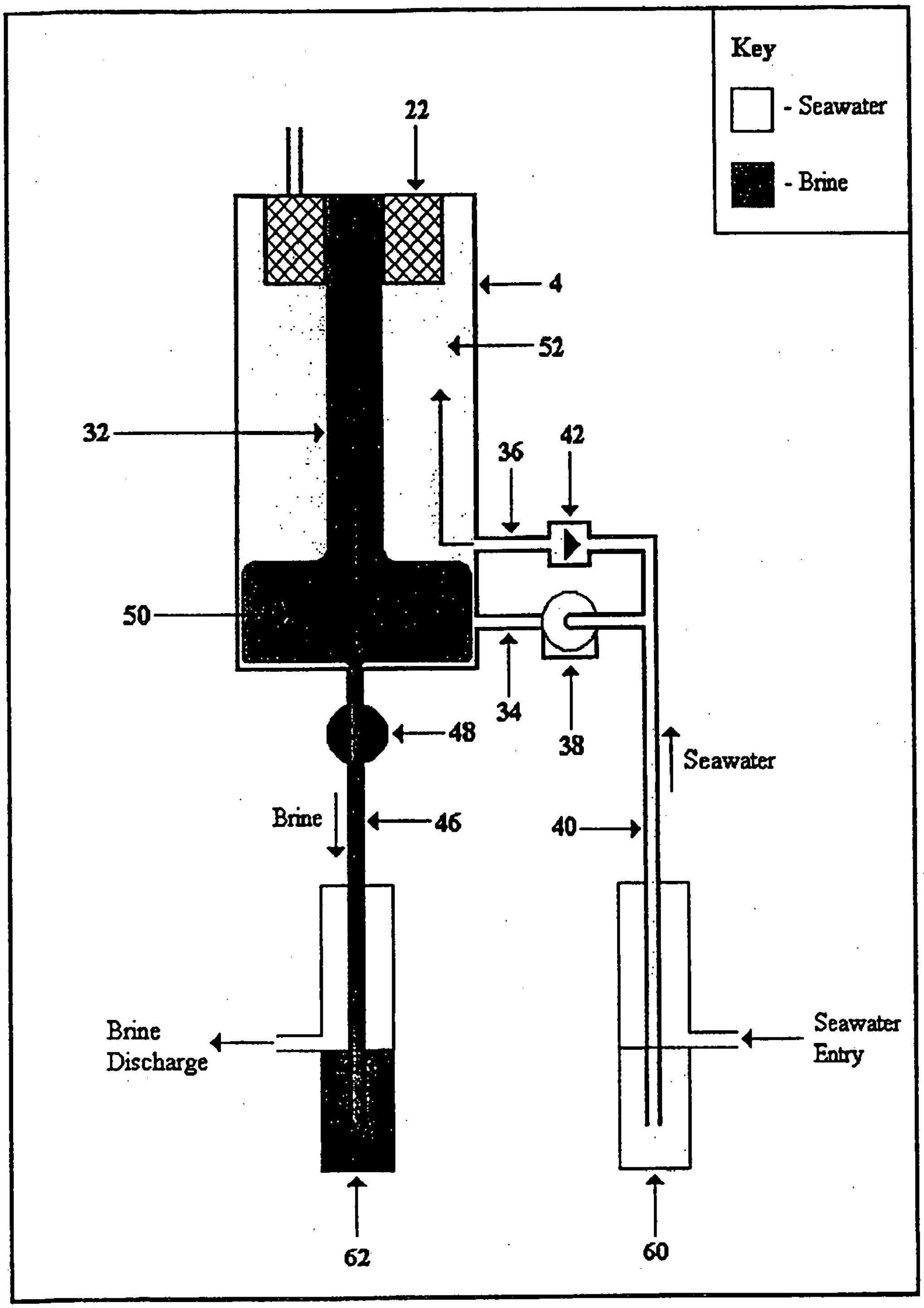

Key
- Seawater
- Brine
22
4
52
32
36
42
50
34
38
48
Seawater
Brine
46
40
Brine
Discharge
Seawater
Entry
62
60

**Figure 7**

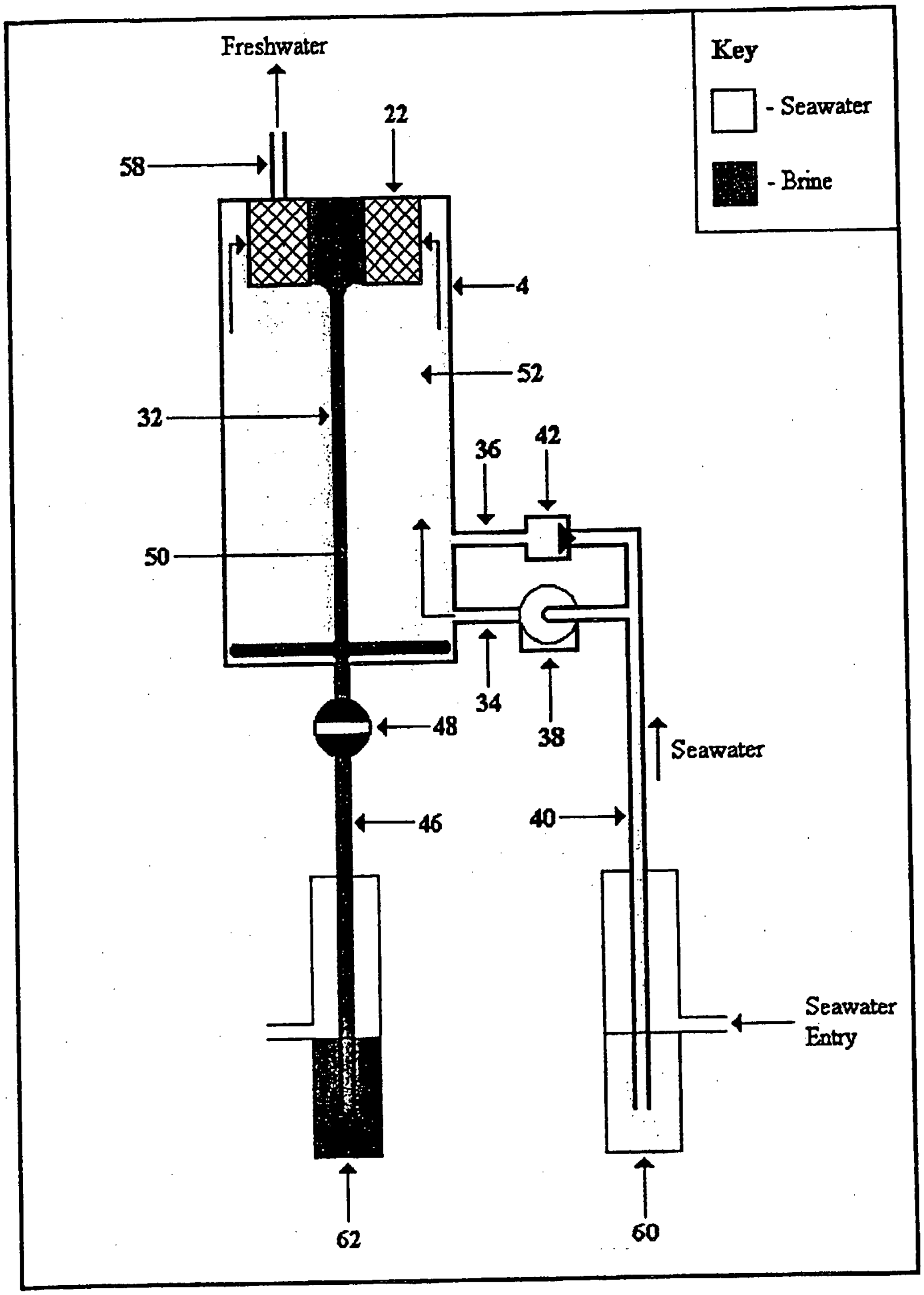
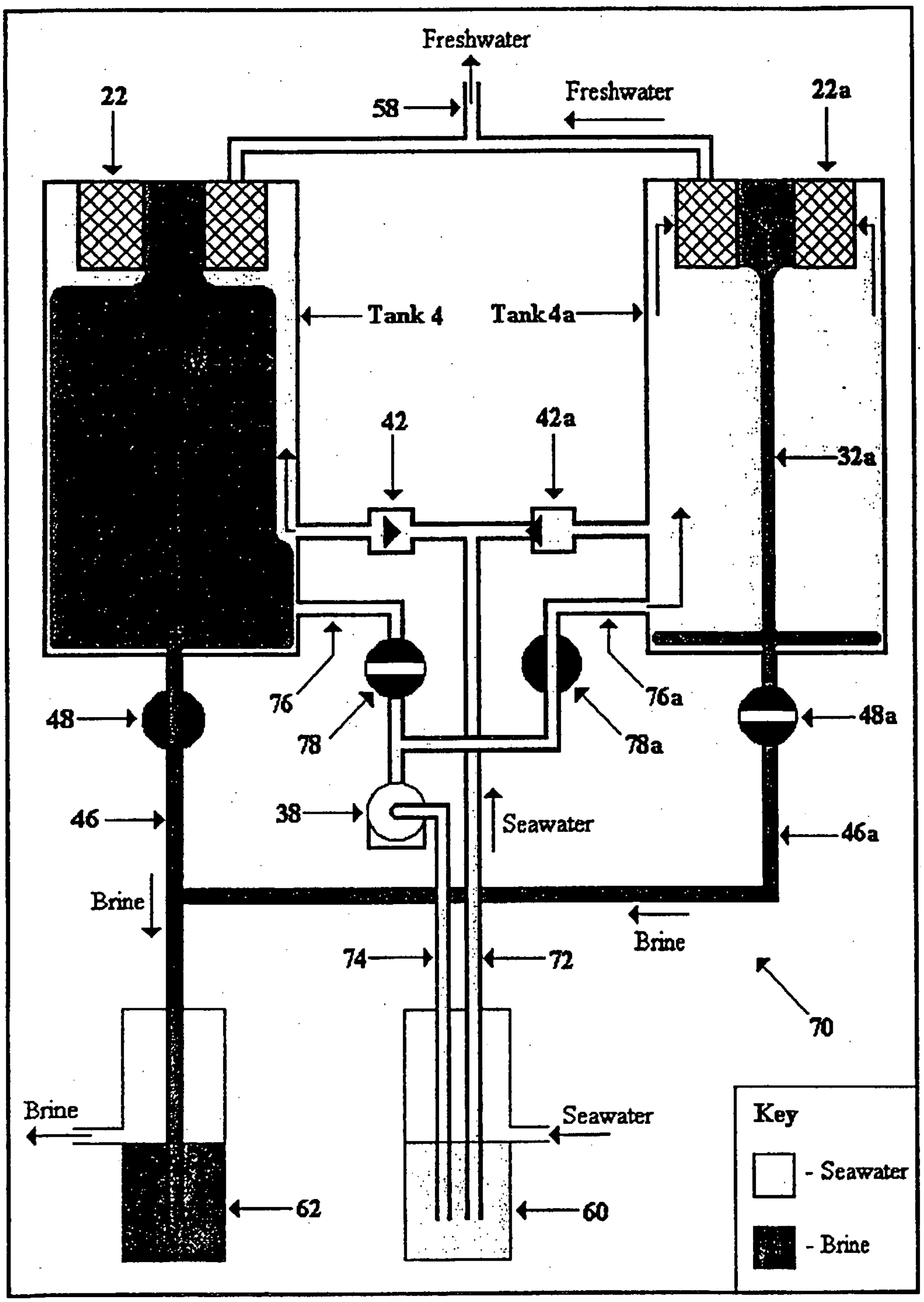

Freshwater
22
58
Key
- Seawater
- Brine
4
52
32
36
42
50
34
38
48
Seawater
46
40
Seawater Entry
62
60

Figure 8


Freshwater
58
Freshwater
22
22a
Tank 4
Tank 4a
42
42a
32a
76
76a
78
78a
48
48a
46
46a
38
Seawater
Brine
Brine
74
72
70
Brine
Seawater
62
60
Key
- Seawater
- Brine

**Desalination System**

The present invention relates to a desalination system, and in particular, but not exclusively to a low energy reverse osmosis water desalination system that utilises hollow fibre ~~separation membranes~~. It also relates to a method for recovering energy used in the desalination system.

The desalination of seawater is an important means of producing potable water in arid countries and islands. A number of alternative technologies are available to produce fresh water from seawater, including evaporation, distillation and separation by means of reverse osmosis membranes.

A major limitation of all desalination systems is the high cost of the energy that is required to produce potable water from seawater. Evaporation and distillation techniques require thermal energy, whilst reverse osmosis processes require electricity to drive the high pressure pumps used in these particular systems. In order to produce cost effective potable water it is becoming increasingly important that desalination systems incorporate efficient means of recovering the energy used in the process.

Reverse osmosis is a well established desalination technology, which involves pumping seawater, under high pressure, through a membrane separation module. Fresh water, the permeate, leaves the membrane module under relatively low pressure, whilst concentrated brine, the retentate, leaves the module under high pressure, albeit at a lower level than the original seawater supply pressure. If the reject brine were discharged straight into the sea, the energy in the brine, in the form of pressure in the retentate brine stream, would be lost, which would result in an inefficient desalination process with high energy costs.

High pressure, up to 80 bar, is required to force seawater through a typical reverse osmosis membrane. This pressure is required to overcome the osmotic pressure of the seawater and to provide an adequate flow of permeate fresh water from the membrane separation module. Spirally wound types of membrane are currently the most widely used for seawater desalination, although hollow fibre membranes are also technically capable of being used in this type of application.

It is acknowledged that a reverse osmosis desalination process can be made more efficient by making use of the pressure available in the retentate brine stream after it has been discharged from the membrane separation module. Utilising the retentate brine pressure to perform work in the reverse osmosis process itself can provide a significant degree of energy recovery, thereby reducing the demand for

electricity within the desalination system. Various methods of energy recovery have been applied to reverse osmosis desalination systems, including turbines, Pelton wheels, reverse running pumps and reciprocating pistons.

The use of different energy recovery techniques has resulted in a gradual decline over recent years in the amount of electrical energy needed to operate reverse osmosis desalination processes, from about 10 kWh/cubic metre of fresh water, down to under 3 kWh/cubic metre when using the latest reciprocating piston energy recovery systems. The electrical requirement quoted here is for the reverse osmosis desalination process only and does not include the energy needed for either the pre-treatment of the seawater (extraction from the sea, filtration, chemical treatment) or the post-treatment (storage, distribution) of the desalinated potable water.

However, even with the latest reciprocating piston energy recovery systems, three pumps are usually required in the desalination system, namely a seawater supply pump, a high pressure pump and a boost pressure pump. The need to use three pumps in a reverse osmosis desalination system still places high electrical energy demands on the process.

In an earlier patent application by the Applicant, GB 0015112.6, an alternative method of recovering energy from a reverse osmosis desalination system is described that requires only two pumps, a supply pump and a high pressure pump, thereby reducing the electrical demand of the system to about 1 .5 kWh/cubic metre of fresh water. This particular patent application describes how the pressure and density of the retentate brine is used to displace seawater, contained in a storage tank, into the seawater supply stream leading to a reverse osmosis module, and a means of increasing the pressure of said seawater, by the application of an additional load to the seawater in the tank, so that a boost pressure pump is not required in the system. This particular system would normally operate with a number of such storage tanks, working in tandem, in order to provide a constant, high pressure flow of seawater to the reverse osmosis separation module.

The present invention seeks to provide an even more efficient reverse osmosis desalinating system. which is more cost effective and requires less operating electricity than the system described in the Applicant's previous patent application. Viewed from one aspect, therefore, the present invention provides a seawater desalination unit comprising a storage tank having a seawater supply inlet; a membrane separation module mounted in or on said storage tank and having a seawater inlet, a permeate outlet and a retentate outlet; a flexible, impermeable barrier arranged within the tank to define two variable volume chambers within the

tank; the tank seawater inlet and the separation module inlet being in communication with a first of said chambers and the separation retentate outlet being in communication with the second of said chambers.

From a further aspect, the invention provides a method of desalinating seawater comprising filling a storage tank with pressurised seawater, feeding said seawater through a separation module that is located on or in the tank, desalinating said seawater in said separation module to produce a fresh water product stream that exits from said storage tank and a relatively dense, pressurised, retentate brine stream which flows back into the storage tank but is separated from seawater already in the tank by means of a flexible, impermeable barrier, so that said brine acts to assist in displacement of the seawater in the tank into the separation module.

In accordance with the invention, therefore, retentate brine flowing from the separation module acts to displace seawater from the storage tank as it flows into a variable volume chamber defined by a flexible barrier in the tank. This means that the external pressure applied to the seawater by a pump, to force the seawater through the separation module, can be at a lower level than normal, thereby reducing the power requirement of the pump. Also, in contrast to desalination systems that use an energy recovery system that is separate from the reverse osmosis module, such as, for example, reciprocating pistons, the invention has the advantage that extra pipes, their associated electrically operated control valves and additional pumps, are not required to transfer either pressurised seawater from the energy recovery system to the reverse osmosis module or retentate brine from the reverse osmosis module back to the energy recovery system. The preferred unit of the invention therefore requires only a single high pressure pump in the system. The pump, which operates at relatively low pressures, can then both supply and pressurise the seawater to a level above the osmotic pressure of seawater, so that the seawater in the storage tank is able to feed through the reverse osmosis module.

The desalination unit will operate on an intermittent basis. After the storage tank has been filled with seawater, the high pressure pump pressurises the seawater to a level that is sufficient to force the seawater through the separation module, whilst the dense retentate brine, which simultaneously flows from the separation module into the flexible barrier, helps to displace the seawater into the separation module, until such time that the brine has virtually replaced all of the seawater in the tank. At this stage, the pressurisation of the seawater by the pump stops and the desalination process in the separation module ceases. The brine is then discharged from the storage tank, and the tank is recharged with a new batch of pressurised seawater, whereafter separation can recommence.

Preferably the separation module is mounted within the tank, and most preferably at the top of the tank. With such an arrangement the retentate brine can flow downwardly under gravity into the tank from the separation module, displacing seawater upwardly towards the module, whilst the permeate fresh water is conveniently discharged from the tank from the top of the separation module. This provides a particularly compact arrangement, reducing to a minimum the need for additional piping and associated valve work.

From yet further broad aspect, therefore, the invention provides a desalination unit wherein a reverse osmosis desalination module and the means to recover energy from the retentate brine are located within a common tank.

Preferably the separation module incorporates hollow fibre membranes in its construction. By using hollow fibre membranes, the reverse osmosis module is capable of providing high permeability at relatively low operating pressures.

Most preferably the module is constructed in a substantially annular shape, with the hollow fibre membranes arranged in a concentric fashion inside the module. An annular shape is possible using hollow fibre membranes because the hollow fibre membranes are capable of being packed in a concentric manner inside the module. An annular separation module is particularly beneficial because it can conveniently fit inside a cylindrically shaped storage tank.

Such a construction is novel in its own right so from a further aspect the invention provides an annular reverse osmosis desalination module incorporating hollow fibre membranes.

Preferably the module is arranged such that pressurised seawater in the tank can flow into the module through the outside wall of the module, whilst retentate brine flows out from the inside wall of the module into the second chamber defined by the flexible barrier member. Accordingly, in the preferred embodiment, the seawater inlet to the separation module is arranged on the radially outer surface of the module, and the retentate brine outlet on the radially inner surface of the module. The outlet for the desalinated water may be provided in the top of the module, extending out through the top of the storage tank.

The membrane module may be made quite compactly, and typically may have a height of about 20 centimetres, an external diameter of about 40 centimetres and an internal diameter of about 30 centimetres.

The flexible barrier member inside the storage tank, which separates the retentate brine from the pressurised seawater in the tank being fed to the separation module, is made from a flexible, impermeable material, for example a polymer material, and is preferably substantially tubular in form. Most preferably, in its

fully extended state the barrier is sized and shaped as to be able to approximately fit the internal contours of the storage tank.

Preferably the barrier is mounted underneath the reverse osmosis module, most preferably in a manner that provides an opening to allow retentate brine to flow from the module into the central space of the barrier. The bottom of the barrier may be suitably attached to the base of the tank, in such a manner as to provide an exit orifice to allow the brine to be discharged from the bottom of the tank when the internal space of the barrier member becomes full of brine.

The storage tank is preferably constructed as a metal pressure vessel, which is equipped with one or more inlets in its wall allow the tank to be filled with seawater, an outlet at the top of the tank for the discharge of desalinated potable water and a separate outlet at the base of the tank to allow retentate brine to be discharged from the tank, as and when appropriate.

Preferably the storage tank is circular in cross-section and in an upright position during the desalination operation to allow gravity to assist in the discharge of the retentate brine.

Preferably the storage tank has two filling pipes located in the wall of the tank to allow the tank to be filled with seawater. Most preferably one of the pipes is connected to a high pressure pump for supplying seawater. That pipe may also be fitted with an electrically operated valve. The other filling pipe is preferably fitted with a unidirectional pressure activated valve allowing seawater to be admitted through the pipe when the pressure in the tank is reduced. This can be achieved by arranging the brine discharge line and the seawater supply line so as to provide a syphon effect within the system. In particular, reduced pressure can be produced in the tank as the relatively dense retentate brine is being discharged from the storage tank to a brine reservoir, so as to permit seawater to be drawn into the tank from the seawater reservoir by a syphon effect, through the unidirectional pressure valve without any assistance from the high pressure pump in the system.

The tank is preferably also provided with an exit pipe at the top of the tank to allow for the discharge of fresh water from the separation module, and an exit pipe at the base of the tank to allow for the discharge of brine from the barrier liner when said liner is full of brine.

Typically the storage tank would be about 2.4 metres high and 1.2 metres in diameter, with an approximate internal storage capacity of 2.5 cubic metres. A desalination unit based on a storage tank of these dimensions, and fitted with the aforementioned size of annular hollow fibre reverse osmosis module i.e. height 20 centimetres, external diameter 40 centimetres, internal diameter 30 centimetres,

would be capable of producing about 500 cubic metres of potable water per day from a supply of typical seawater.

The effect of the brine displacing seawater into the separation module and the aforementioned siphon effect mean that only one high pressure pump is required in the system. The primary function of the pump is to pressurise the seawater in the storage tank to an extent that is sufficient to overcome the osmotic pressure of the seawater, so that the seawater can feed through the reverse osmosis module, whilst simultaneously producing an adequate flow of fresh water from the separation module. During the desalination process, the pump also continues to replenish the storage tank with new seawater, equivalent to the volume of permeate fresh water that is being discharged from the separation module.

Whilst desalination can be effected using a single unit as described above, in order to obtain higher volumes of potable water, preferably a plurality of units are operated in tandem. To assist in the continuity of flow of potable water, the units are preferably operated out of phase, i.e at different stages of operation, for example one might be filling with seawater, another desalinating pressurised seawater in the reverse osmosis module, and another discharging retentate brine.

Preferably a single high pressure pump is employed to supply seawater to all the units. Preferably the pump operates continuously, and hence efficiently, to supply and pressurise individual storage tanks with seawater, as and when appropriate.

The system further preferably comprises a series of synchronised valves, to control the supply of pressurised seawater to the storage tanks and the discharge of brine from the tanks. In particular, each unit is preferably equipped with an electric valve to control the discharge of retentate brine from the tank and a further electric valve to control the supply, and pressurisation, of seawater to the tank. The desalination system in accordance with the invention is therefore a relatively low pressure, and hence low energy, desalination process, which basically requires only one high pressure pump in the system.

Preferably the seawater supplied to the units uses a common seawater reservoir chamber and common seawater supply pipes, and the retentate brine is discharged through a common discharge pipe system to a common brine reservoir.

The invention will now be described, by way of example only, with to the accompanying schematic illustrations where:

Figure 1 is a cross-section illustration of a desalination unit in accordance with the invention;

Figures 2 to 7 illustrate the operation of an individual desalination unit at

different stages in its process cycle; and

Figure 8 illustrates a desalination system comprising a plurality of desalination units as shown in Figure 1.

Figure 1 shows a cross-sectional view of a typical desalination unit 2 in accordance with the invention. The unit 2 comprises a metal, pressure resistant storage tank 4 constructed from a cylindrical body 6 closed by a base plate 8 and a top plate 10. The cylindrical body 6 is joined to the plates 8, 10 by means of suitable fastenings, 12, 14, such as, for example, nuts and bolts. The fastenings 12, 14 locate through bores in the plates 8, 10 and 6 that correspond with bores in flanges 16, 18 extending outwardly from the top and the base of cylinder 6. The flanges 16, 18 preferably extend completely around the circumference of cylinder 6. Sealing rings 20 are provided between the flanges 16, 18 and the opposed plates 8, 10.

A reverse osmosis separation module 22 is attached to the underneath of the top plate 10. Module 22 is annular in form and contains hollow fibre separation membranes. The separation module 22 is located centrally under top plate 10. Seawater can enter the module 22 through ports 24 located in the outside wall 26 of the module 22, whilst retentate brine can discharge from the module 22 through ports 28 located in the inside wall 30 of the module 22, into a flexible barrier 32 located within the tank 4.

Two seawater entry pipes, 34, 36, are located in the cylindrical wall 6 of the storage tank 4. A high pressure pump 38 is located in the entry pipe 34 so that the pump 38 can supply seawater from a seawater supply pipe 40 and also pressurise the seawater in the tank 4. A unidirectional, pressure activated, valve 42 is located in the entry pipe 36.

The storage tank 4 has an exit pipe 46 positioned in the centre of the base plate 8 and an electrically operated valve 48 is fitted in the exit pipe 46. The exit pipe 46 and valve 48 allows for the discharge of retentate brine, as and when appropriate, from the interior space 50 defined within the flexible barrier 32.

As shown in Figure 1, the barrier 32 is tubular in shape in its fully extended state. It divides the interior of the tank into an interior space 50 and an exterior space 52. The top of the barrier 14 is attached to the base of the separation module 22 in such a manner that it forms an opening 54 to allow retentate brine to flow into the interior space 50 from the module 22. The bottom of the barrier member 32 is attached to the base plate 8 in such a manner that it forms an opening 56 to the exit pipe 46, so that brine can to be discharged from the space 50 as and when appropriate through the pipe 46.

Finally, a desalinated water outlet pipe 58 extends upwardly from the

module 22 through the top plate 10.

The mode of operation of the unit of Figure 1 will now be fully described with reference to Figures 2 to 7.

Figure 2 shows the desalination unit in its initial, empty, condition. Seawater (pre-filtered and treated as necessary) has already been introduced into a reservoir chamber 60. The seawater supply pipe 40 is empty, pump 38 is non-operational and the unidirectional pressure valve 42 is closed. The electrically operated brine discharge valve 48 is closed, and the brine discharge pipe 46 and the brine reservoir chamber 62 into which brine is discharged are also empty. The storage tank 4 is empty and the barrier member 32 is in its collapsed, empty state.

Figure 3 illustrates the initial filling of storage tank 4 with seawater. During this phase, the tank 4 is filled with seawater by the pump 38, which draws seawater from the seawater reservoir 60 up the seawater supply pipe 40 and then feeds the seawater through pipe 34 into the external space 52 defined within the tank 4.

During the initial charging of the system, feed pump 38 pressurises the seawater in the tank 4 to a pressure just below the osmotic pressure of seawater, i.e. about 20 bar for normal seawater. The pressure applied by the pump 38 to the seawater inside tank 4 ensures that the unidirectional pressure valve 42 in the pipe 36 remains shut, so that seawater cannot return through that pipe 36 to the reservoir 60. At this stage, the barrier member 32 is fully collapsed, and the brine discharge valve 48 in the pipe 46 is closed.

In the operational state shown in Figure 4, the pressure inside storage tank 4 is increased by the pump 38 until the pressure of the seawater in the exterior space 52 reaches about 20 bar above the osmotic pressure, i.e. an operating pressure of about 40 bar. At this increased pressure, the seawater starts to penetrate through the outside wall of the separation module 22, dense, pressurised, retentate brine starts to flow from the inside wall of the separation module 22 into the interior space 50 defined by the barrier member 32, and permeate fresh water discharges from the separation module 22 through the pipe 58 at sufficient flux to provide an adequate flow of potable water.

The brine, which is under pressure and which is denser than the seawater in the space 52 outside the barrier 32, starts expanding the barrier member 32, and in so doing aids the displacement of the seawater in the space 52 upwardly into the separation module 22. The pump 38 continues to replenish the space 52 with new seawater, equivalent to the volume of permeate fresh water that is being discharged through the pipe 58, and the pressure applied by pump 38 is maintained at a level that is sufficient to provide effective desalination in the separation module 22, whilst

giving an adequate discharge of fresh water from the pipe 58. At this stage, the pressure in the tank 4 keeps the unidirectional pressure valve 42 closed, and the brine discharge valve 48 is maintained closed.

In the state shown in Figure 5, the barrier member 32 is completely filled with brine and at this stage pump 38 ceases operation. The pressure in the external space 52 of the tank 4 is no longer sufficient to overcome the osmotic pressure of the seawater, and the seawater remaining in the tank 4 is unable to feed through the hollow fibre membranes in the separation module 22. Accordingly desalination in the module 22 ceases, so that permeate fresh water and retentate brine are no longer discharged therefrom. Because of the residual pressure in tank 4, the unidirectional pressure valve 42 remains closed. The brine discharge valve 48 remains closed.

In the state shown in Figure 6, the electrically operated brine discharge valve 48 is opened and the dense brine is discharged from the internal space 50 of the barrier member 32 through the pipe 46 into the brine reservoir chamber 62. The brine discharge pipe 46 and the brine reservoir 62 fill with brine. The seawater supply pipe 40 and the brine discharge pipe 46, as well as the seawater reservoir 60 and the brine reservoir 62, have been arranged so that when the brine reservoir 62 is full, a syphon is formed between the brine discharge and the seawater supply.

As the brine initially discharges from the internal space 50 of the barrier member 32, the barrier member 32 starts to collapse and the pressure in the tank 4 drops rapidly. The drop in pressure in tank 4 allows the unidirectional pressure valve 42 to open, so that a new batch of seawater is drawn into the tank 4, through the pipe 36, by the syphon effect formed between the discharge of the relatively dense brine and the new supply of seawater. At this stage, the pump 38 will usually be non-operational. While the tank 4 is filling with a new batch of seawater, the pressure in the tank 4 is not high enough to force seawater through the separation module 22 and there is no discharge of either fresh water or brine from the module 22.

In the state shown in Figure 7, the barrier member 32 has collapsed once again and is virtually empty of brine. The electrically operated brine discharge valve 48 has been closed once again and the tank 4 has been filled with a new batch of seawater. The pump 38 pressurises the seawater in the external space 52 of the tank 4 until the pressure is higher than the osmotic pressure of the seawater, so that desalination of the seawater in the separation module 22 can recommence. Permeate fresh water once more starts to flow from pipe 58 and dense brine discharges from the inside wall of module 22 into the barrier member 32. The pressure of the seawater is maintained by pump 38 at a level that sustains the

desalination process, and pump 38 also replenishes the tank 4 with new seawater, equivalent to the volume of fresh water being discharged from the separation module 22 through pipe 58. The pressure applied by pump 38 has once more closed the unidirectional pressure valve 42 so that seawater is prevented from leaving storage tank 4, through the pipe 36.

The seawater desalination process will then proceed continually, albeit intermittently, by repeating the operational sequences described in Figures 3 to 7 inclusive, except that the brine discharge pipe 46 and the brine reservoir 62 will always be full of brine, and the seawater supply pipe 40 and the seawater reservoir 60 will always be full of seawater. This ensures that when brine is periodically emptied from tank 4, a syphon effect is constantly maintained between the brine discharge and the seawater supply, so that tank 4 can be filled with a new batch of seawater without the assistance of the pump 38.

The unit above, operating in isolation will produce only an intermittent flow of desalinated water. Figure 8 shows how two such desalination units can be operated in tandem, to produce a more continuous supply. Although two units are disclosed in the Figure, it serves to illustrate general principles which could be applied to any number of units being operated together in series.

The system 70 includes two tanks 4, 4a and has two seawater supply pipes 72, 74. The pipe 72 supplies seawater from the seawater reservoir 60 to unidirectional pressure activated valves 42 and 42a. The pipe 74 supplies seawater from the seawater reservoir 60 to a single high pressure pump 38. Supply lines 76, 76a lead to the respective tanks 4, 4a through respective electrically controlled supply valves 78, 78a..

As shown in Figure 8, tank 4 is virtually full of brine and the tank 4a is virtually full of seawater. The electric brine discharge valve 48 in the brine discharge pipe 46 from tank 4 has just opened and brine has started to flow from the tank 4 to the brine reservoir chamber 62. The supply valve 78 between pump 38 and tank 4 is closed at the same time as the brine valve 48 is opened.

The drop in pressure in the tank 4, following the discharge of brine from the tank 4 by opening the valve 48, has allowed the unidirectional pressure activated valve 42 to open, and the syphon effect between the brine discharge and the seawater supply draws in a new batch of seawater, up supply pipe 72, into the tank 4.

In tank 4a, the brine has just been discharged from the tank into the brine reservoir 62 and the brine discharge valve 48a in the brine discharge pipe 46a has just been closed. During the discharge of the brine from tank 4a, a new batch of

seawater has been drawn up the supply tube 72 into tank 4a, by the syphon effect between the brine discharge and the seawater supply, through the pressure activated valve 42a.

At the same time as electric valve 78 to tank 4 was closed, valve 78a to tank 4a was opened, allowing pump 38 to pressurise the seawater in tank 4a until desalination starts in the reverse osmosis module 22a. When operating desalination units in tandem, pump 38 can be maintained at a constant relatively low pressure of about 30 bar.

The pressure applied to the seawater in tank 4a by pump 38 has closed the pressure activated valve 42a so that seawater cannot drain from tank 4a back to the seawater reservoir 60. Permeate fresh water flows from the separation module 22a into the discharge pipe 58. Pump 38 continues to pressurise the seawater in tank 4a, whilst replenishing tank 4a with new seawater, drawn up supply pipe 74, to replace the fresh water being discharged from the separation module 22a.

The process then continues until such time that the brine has fully discharged from tank 4, at which stage valve 48 closes, and tank 4 has been recharged with a fresh batch of seawater, whilst the barrier 32a in tank 4a has been completely expanded by the retentate brine flowing from module 22a. When this stage is reached, the process is reversed between the two tanks, by simultaneously activating the appropriate electrical control valves, i.e. the desalination process is initiated in tank 4 by opening valve 78 and using pump 38 to pressurise the seawater in tank 1, whilst valve 78a is closed to prevent seawater entering tank 4a. The brine in tank 4a is then discharged from tank 4a by opening valve 48a, and tank 4a is refilled with a new batch of seawater through the open pressure activated valve 42a.

The desalination system will then operate on a continuous basis, by electronically controlling the electric valves so as to allow the brine discharge, seawater filling and desalination sequences to be switched between the two tanks, as and when appropriate.

Figure 8 illustrates two desalination units operating in tandem. In practice, there may well be more than two units, operating sequentially in series, at different stages in their operational cycle.

The efficiency of the combined hollow fibre reverse osmosis desalination system and energy recovery process and its effect on reducing electricity demand is illustrated in Table 1, which summarises the estimated working pressures and electricity consumption needed to desalinate normal seawater with a saline concentration of 3.5% by mass. The electrical energy requirement shown in Table 1 is for the reverse osmosis desalination system only and does not include the energy

required for either the pre- or post-treatment of water, or the small amount of electricity required to operate the electric valves used in the system.

**Table 1**
**Breakdown of working pressure and electrical energy demand for normal seawater**

| Measurement | Value |
|---|---|
| Water salinity, % mass | 3.5 |
| Water flux through high-pressure pump, gpm | 0.0166 |
| High-pressure pump pressure, psi | 503 |
| High-pressure pump efficiency, % | 70 |
| High-pressure pump energy requirement, kW | 0.00479 |
| Desalinated water flux, gpm | 0.0166 |
| **Total energy demand, kWh/cubic metre** | **1.38** |

Table 1 shows that the proposed reverse osmosis desalination system is extremely efficient and has an electrical energy requirement of only 1.38 kWh/cubic metre of water, when desalinating normal seawater with a salt concentration of 3.5%. The proposed integrated reverse osmosis and energy recovery system uses significantly less electrical energy that the desalination system described in the Applicant's earlier patent application. The proposed system is also believed to be much more energy efficient than alternative desalination systems that are currently commercially available to desalinate seawater, whether these be based on reverse osmosis technology or on other desalination techniques.

The proposed desalination system has the additional benefit that it is an integrated desalination and energy recovery system, and no pipes are required to move either pressurised seawater or pressurised brine between the reverse osmosis module and the energy recovery system. Desalination systems that rely on an energy recovery process that is separate from the reverse osmosis system do, however, require pipes to move seawater and brine between the energy recovery process and the reverse osmosis module. The flow of water into and out of these pipes usually has to be regulated by a multiplicity of electrically operated control valves and additional pumps may also be required to transfer seawater and brine around the system. In contrast, the proposed integrated desalination and energy recovery process requires only one high pressure pump in the system and only a

limited number of electrically operated valves are used in the system.

Although the amount of electricity required to operate valves is relatively minor, the proposed integrated desalination system will nevertheless be more efficient in this respect than systems that operate with a separate energy recovery process.

In addition to seawater, which can contain varying concentrations of salt, the low energy desalination system described could be used to obtain fresh water from brackish water and could also be used in any application where the level of salts in the in-feed water needs to be reduced to a lower concentration in the permeate coming from the system. The term seawater should therefore be construed broadly so as to embrace these situations.

It will be seen that the described method of reverse osmosis desalination and energy recovery requires only a limited number of electrically operated valves in the system, to control the supply of seawater to a storage tank and the discharge of retentate brine from the tank, as and when appropriate, and only a single high pressure pump to pressurise the seawater in the tank to enable the seawater to pass through the reverse osmosis separation module.

The preferred embodiment uses a reverse osmosis desalination module that utilises hollow fibre separation membranes and which is located inside a storage tank that contains seawater, which has been pressurised by a pump that operates at relatively low pressures. The seawater feeds through the separation module, and the energy in the retentate brine coming from the reverse osmosis module is recovered by returning the brine to the storage tank and using the density, pressure and volume of the brine to help displace the seawater in the tank into the reverse osmosis module. The brine and seawater inside the storage tank are separated from each other, by means of a flexible, impermeable barrier which is located inside the storage tank in such a manner that the liner is able to freely expand and contract with the tank.

A further advantageous feature of the described arrangements is that relatively few electrically operated valves are required in the system. Once the system is in continuous operation, the pressure applied by the high pressure pump to the seawater in the tank only needs to be at a level that is sufficient to feed the seawater through the reverse osmosis module and provide an adequate flow of permeate fresh water. The high pressure pump therefore operates at a lower pressure than is normally associated with other forms of commercially available reverse osmosis desalination processes.

The desalination system preferably combines a hollow fibre reverse osmosis

module and an energy recovery process within the same seawater desalination unit, so that no extraneous pipes, electrically operated control valves or additional pumps are required to move pressurised seawater and pressurised brine between the reverse osmosis module and the energy recovery system. Although the desalination system as described preferably utilises hollow fibre membranes as the desalination medium in the reverse osmosis module, the principles of the desalination and energy recovery system, in accordance with the invention, could well apply to other types of separation membrane, such as, for example, plate, tubular and spirally wound forms of membrane.

It is unlikely that the annular separation module as described in the invention could be realised using these alternative forms of membranes due to their methods of manufacture and shape. However, there are various well established module designs to contain the aforementioned alternative membranes, many of which are basically cylindrical in form and which could be adapted so that they are able to fit inside a storage tank as described as described in Figure 1.

While the storage tank described in Figure 1 illustrates one possible design of tank, it will be clear to those skilled in the art that other alternative tank constructions could be considered to provide a suitable pressure resistant storage vessel.

Also, while the flow of seawater has been described as being from the outside to the inside of the module, the arrangement could well be reversed with suitable adaptation of the other parts of the apparatus.

Claims

1. A seawater desalination unit comprising a storage tank having a seawater supply inlet, a membrane separation module provided in or on said storage tank and having a seawater inlet, a permeate outlet and a retentate outlet, a flexible, impermeable barrier arranged within the tank to define two variable volume chambers within the tank, the tank seawater inlet and the separation module inlet being in communication with a first of said chambers and the separation retentate outlet being in communication with the second of said chambers.

2. A unit as claimed in claim 1 wherein the separation module is provided within the tank.

3. A unit as claimed in claim 1 or 2 wherein the separation module is provided at the top of the tank.

4. A unit as claimed in any preceding claim wherein the separation module incorporates hollow fibre membranes in its construction.

5. A unit as claimed in claim 4 wherein the module is constructed in a substantially annular shape.

6. A unit as claimed in claim 5 wherein the hollow fibre membranes are arranged in a concentric fashion inside the module.

7. A unit as claimed in claim 5 or 6 wherein the seawater inlet to the separation module is arranged on the radially outer surface of the module, and the retentate brine outlet is arranged on the radially inner surface of the module.

8. A unit as claimed in any preceding claim wherein the separation membrane module has a height of about 20 centimetres, an external diameter of about 40 centimetres and an internal diameter of about 30 centimetres.

9. A unit as claimed in any preceding claim wherein the flexible barrier member is made from a flexible, impermeable material, for example a polymer material.

10. A unit as claimed in any preceding claim wherein the flexible barrier member is substantially tubular.

11. A unit as claimed in any preceding claim wherein in its fully extended state the barrier is sized and shaped as to be able to approximately fit the internal contours of the storage tank.

12. A unit as claimed in any preceding claim wherein the barrier member is mounted underneath the separation module to receive retentate brine flowing from the module into the central space of the barrier.

13. A unit as claimed in any preceding claim wherein the storage tank comprises one or more inlets in its wall to allow the tank to be filled with seawater, an outlet at the top of the tank for the discharge of desalinated potable water and an outlet at the base of the tank to allow retentate brine to be discharged from the tank.

14. A unit as claimed in claim 13 wherein the brine outlet is provided with a selectively operable valve.

15. A unit as claimed in any preceding claim wherein the storage tank is about 2.4 metres high and 1.2 metres in diameter, with an approximate internal storage capacity of 2.5 cubic metres.

16. A unit as claimed in any preceding claim wherein an inlet to the tank is provided with a one way valve which opens under the reduced pressure in the tank as relatively dense retentate brine is being discharged from the storage tank to a brine reservoir, so as to permit seawater to be drawn into the tank from the seawater reservoir by a syphon effect.

17. A unit as claimed in any preceding claim comprising a single high pressure pump for supplying and pressurising water in the unit.

18. A desalination system comprising a plurality of units as claimed in any preceding claim operating together in tandem.

19. A system as claimed in claim 18 comprising control means to synchronise operation of the respective units.

20. A system as claimed in claim 19 wherein said control comprises a series of synchronised valves, to control the supply of pressurised seawater to the storage tanks and the discharge of brine from the tanks.

21. A system as claimed in claim 18, 19 or 20 comprising a single high pressure pump for supplying seawater to all the units.

22. A method of desalinating seawater comprising filling a storage tank with pressurised seawater, feeding said seawater through a separation module that is located on or in the tank, desalinating said seawater in said separation module to produce a fresh water product stream that exits from storage tank and a relatively dense, pressurised, retentate brine stream which flows back into the storage tank but is separated from seawater already in the tank by means of a flexible, impermeable barrier and which acts to assist in displacement of the seawater in the tank into the separation module.

23. A method as claimed in claim 22 wherein the separation module is provided within the tank.

24. A method as claimed in claim 22 or 23 wherein the separation module is provided at the top of the tank.

25. A method as claimed in any of claims 22 to 24 wherein the separation module incorporates hollow fibre membranes in its construction.

26. A method as claimed in claim 25 wherein the module is constructed in a substantially annular shape.

27. A method as claimed in claim 26 wherein seawater is fed to a radially outer surface of the module, and the retentate brine outlet flows out from the radially inner surface of the module.

28. A method as claimed in any of claims 22 to 27 wherein the flexible barrier is substantially tubular and in its fully extended state the is sized and shaped as to be able to approximately fit the internal contours of the storage tank.

29. A method as claimed in any of claims 22 to 28 wherein the seawater supply

to and the retentate brine flow from the tank are arranged to produce a syphon effect to permit seawater to be drawn into the tank.

30. A method as claimed in any of claims 22 to 29 wherein a number of tanks are operated in tandem, and wherein the supply of seawater to and the removal of retentate brine from the tanks is synchronised.

31. A method of desalinating seawater comprising:

- feeding a storage tank with seawater;
- pressurising said seawater in the tank by means of a high pressure pump;
- feeding said pressurised seawater into a hollow fibre reverse osmosis module located within the storage tank;
- desalinating said seawater in said separation module to produce a permeate fresh water product stream and a dense, high pressure retentate brine stream;
- feeding said brine stream into a chamber defined by a flexible, impermeable barrier liner, also located inside the storage tank, said liner separating said brine from said seawater already in the tank;
- allowing said brine, as it fills said barrier liner, to help displace said seawater into said separation module;
- maintaining the pressure in said tank by said pump at a level sufficient to sustain the reverse osmosis desalination process, whilst simultaneously replenishing said tank by said pump with new seawater equivalent to the permeate fresh water being discharged from said separation module;
- discharging said brine from the flexible, barrier liner, when it is full, so that said brine is discharged from the base of the storage tank to a brine reservoir chamber;
- discharging said brine from the storage tank in a manner such as to provide a syphon effect with the seawater supplied to said tank, so that as said brine is discharged from said tank a new batch of seawater is drawn into said tank;
- repeating the desalination cycle.

32. A method as claimed in claim 31, wherein a plurality of such desalination units are operated sequentially in tandem by means of electronically controlled valves, and wherein the same high pressure pump is used to provide the pressure

requirements of said desalination units.

33. A desalination unit wherein a reverse osmosis desalination module and a means to recover energy from retentate brine are located within a common tank.

34. A unit as claimed in claim 33 wherein said energy recovery means comprises a flexible barrier defining a chamber for receiving retentate brine, the barrier displacing seawater into the module as it fills with brine.

35. An annular reverse osmosis desalination module incorporating hollow fibre membranes.

The Patent Office

PATENTS • DESIGNS • COPYRIGHT • TRADE MARKS

INVESTOR IN PEOPLE

**Application No:** GB 0118253.4
**Claims searched:** 1-32, 34

**Examiner:** Chris Archer
**Date of search:** 17 April 2002

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): C1C (CRL, CSL); U1S (S1250)

Int Cl (Ed.7): C02F (1/44)

Other: ONLINE: WPI, EPODOC, JAPIO

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| X | US 4604194 | (ENTINGH) see in particular tank 18 and flexible barrier 96 in the figure | 1 at least |

| | | | |
|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| | | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |
| & | Member of the same patent family | | |